CHASSIS Lubricate for SAFETY every 1,000 MILES LUBRICATION

The Institute Spokesman

Published by NATIONAL LUBRICATING GREASE INSTITUTE

VOLUME IX • NUMBER 4 JULY, 1945

Notes on the Operation and Applications of the S. O. D. Pressure Viscometer

By J. C. ZIMMER *and* J. B. PATBERG

Esso Laboratories — Standard Oil Development Company Research Division

Presented at 12th Annual Meeting, N. L. G. I.

I. INTRODUCTORY

The prime function of a lubricating material is that of minimizing friction between bearing surfaces. The choice of a lubricant is governed primarily by two opposing limitations; it must be sufficiently "thin" or fluid to give the least possible frictional drag, and yet, sufficiently heavy to prevent its displacement or removal from the bearing surfaces. The basic property of the lubricant connected with these limitations is VISCOSITY.

Viscosity is defined as the resistance to flow, or internal friction, and for true liquids is independent of other conditions at specific temperatures and pressures. The viscosity coefficient is defined by Poiseuille's equation, $\eta = \frac{\pi PR^4}{8L\ v/t}$, which is derived from capillary flow of liquids. The dimensions of (η) are m $l^{-1}t^{-1}$, gram/cm./sec. The unit is the poise, one dyne-second per $cm.^2$, and is defined as the viscosity exhibited by a liquid which gives a flow resistance of one dyne per $cm.^2$, unit *shear stress*, when the *rate of shear* is unity, or 1 $sec.^{-1}$. Kinematic viscosity is the ratio η /d, viscosity over density. *Newton's law of flow may be stated:* The ratio of shear stress to rate of shear is equal to a constant or $\eta = F/S$, where (η) is the viscosity coefficient. In capillary flow the *shear stress* is arbitrarily taken as the force per unit area distributed over the walls of the capillary; the total pressure, P (dynes/$cm.^2$), times the cross sectional area of the tube (πR^2), divided by the area of the cylinder formed by the walls of the tube ($2\pi RL$). Thus, $F = \frac{PR}{2L.}$ Substituting in Poiseuille's equation we obtain $\eta = \frac{F}{4\ v/t,/R^3}$, which when combined with Newton's law gives $S = \frac{4\ v/t}{\pi R^3}$, the *rate of shear* at the walls of the tube. For Newtonian fluids the rate of shear at any point in the tube may be calculated, but for plastic or non-Newtonian fluids this arbitrary means of shear rate specification is considered satisfactory. Greases are known to be non-Newtonian, and since their viscosity changes with the rate of shear, they possess no true viscosity coefficient. For materials which behave in this manner the term "apparent viscosity" $(\eta\alpha)$ is now generally applied to the ratio of shear stress to rate of shear. In order for the apparent viscosity to have any significance it is, of course, necessary to specify the rate of shear at which the determination was made.

The viscosity data are conventionally plotted on log-log paper, apparent viscosity versus rate of shear, and the resulting curve is characteristic of the grease with respect to its general type and its previous history. The characteristics of the viscosity-shear curve are primarily a function of the soap content and the oil viscosity, although the type of soap is also of considerable importance. With a given type of soap the apparent viscosity is largely dependent on the amount of soap at low rates of shear and the viscosity of the base oil at high rates of shear. With different soaps considerable variation is shown in the rate of change of viscosity with rate of shear. All of this, of course, assumes that the previous history of the several lubricants which are being compared is substantially the same for it is known that such things as the efficiency with which the soap is used, degree of working during manufacture and packaging, as well as cooling rate, do affect the grease structure and this shows up in the viscosity-shear diagram. If the grease is extremely susceptible to oxidation or oil leakage, the viscosity will change accordingly, but this amounts to a change in composition, and where such changes occur, the grease is usually considered to be unsatisfactory for most purposes.

The complexity of the problem serves to stress the importance of having a method that will show up the major factors which are known to affect the lubrication properties of greases. The viscosity under stress appears to be one of the most indicative qualities in determining a grease's suitability for a particular application, certainly more so than the relatively non-informative penetration value.

Another important property of a grease is its *yield value*, but the method of determination of this property is less generally agreed upon. The yield value is defined, categorically, as the stress necessary to initiate flow. For true plastics this value is quite definite and easily measured, but for

(Continued on Page 3)

Torque-Viscosity Characteristics of Lubricating Greases

By L. C. BRUNSTRUM, E. W. ADAMS AND E. E. ZIEGLER
Of Research Laboratories of Standard Oil Company (Indiana)

(Continued from June Issue)

Evaluation of the constant was carried out as follows:

The oil used in grease B was frozen in the bearing at about −100 degrees F, placed in the machine and warmed to the test temperature. The bearing was then tested at −50 degrees F and 2 rpm. By multiplying the equilibrium torque x 30, the time for one revolution at 2 rpm, a value is obtained which is equivalent to the regular "plasticity number." When this value is multiplied by ten, it falls approximately on the extrapolated oil viscosity. Accordingly this factor is a satisfactory empirical conversion from "plasticity number" to Saybolt viscosity.

This value was also obtained by another method. It is now generally known that the grease viscosity approaches the oil viscosity at high shear rates (also at low temperatures, the latter making the oil viscosity extremely high.) The former situation was simulated by running grease A at a higher temperature, at which the oil viscosity was relatively low, and at very high shear rate. In this case the bearing was operated at 1800 rpm. A value which agrees quite well with the oil viscosity is obtained after the "plasticity number" so determined is multiplied by ten. The two values shown in Figure 7 represent tests with and without side shields. It should be pointed out that this method of evaluating the constant is quite accurate because of the extended scale used on the lower portion of the ASTM chart. The actual torque x time values of 11 and 15 would be far off the bottom end of the scale if the factor of 10 had not been employed.

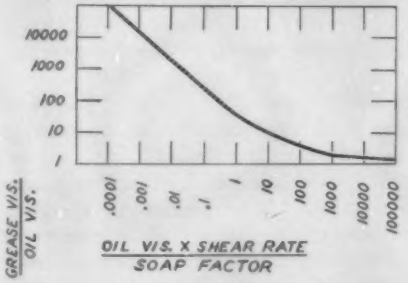
The equilibrium torque values used to calculate the viscosities shown in Figure 7 are taken from charts typified by Figure 5 at 5 minutes. Actually there is a very slight decrease in torque after five minutes which is believed to represent a slow increase in temperature of the bearing. When the "plasticity number" so obtained (torque x 30) is multiplied by 10 it will be seen that the grease viscosity has a straight line temperature relationship until it reaches approximately to the viscosity of the oil contained in the grease. From this point on, further changes in the viscosity of the grease are controlled by changes in the viscosity of the oil. The shape of this whole curve at the high viscosities in question would be roughly the same had the values not been multiplied by ten, but the grease viscosity would have been below the extrapolated oil viscosity. This is additional reason for believing that the factor of ten is approximately correct.

It is of interest to compare the shape of this viscosity-temperature curve with published data on apparent viscosity of greases.

Arveson[2] has shown the apparent viscosity of a whole series of greases at varying temperatures can be represented by a single line by plotting the ratio of $\frac{\text{grease vis.}}{\text{oil vis.}}$ versus $\frac{\text{oil vis. x shear rate}}{\text{soap factor}}$. This curve (Figure 8)

FIG. 8

VISCOSITY-SHEAR RELATIONSHIP



shows that at either high shear rate or high viscosity (heavy oil or low temperature) the grease viscosity approaches the oil viscosity. Cooling a grease and testing its viscosity at constant shear rate is equivalent to moving along the curve from left to right (soap factor changes only slightly with temperature). By arbitrarily selecting, for example, and oil viscosity of 1,000,000, a soap factor of 100 and a shear rate of 10, would be at the right side of the chart. In other words, the grease viscosity and oil viscosity would be nearly equal. Further cooling of the grease will result in viscosity changes which are controlled by and are equal to the change in oil viscosity. If this were not true, the grease viscosity would be less than the oil viscosity if the grease viscosity-temperature curve is extended indefinitely to the left in Figure 7.

Since "plasticity numbers" are really apparent viscosity, the above considerations show why the values on torque devices approach the extrapolated oil viscosity lines. This same technique has been applied to dispensing data and for this report it is sufficient to say that curves similar to the "plasticity number"—temperature curve of Figure 7 are obtained.

IV. CONCLUSIONS

The reader is again requested to examine Figure 7 while the following summary is being made:

1. The torque value of any grease at a given temperature (above its plasticity point) is any value from some high figure (depending on soap content) to almost the viscosity of its oil and depends on the shear rate of the test.
2. Torque values obtained in a 204 bearing at 2 rpm and converted to viscosity have about the same temperature-viscosity slope as pressure viscosity lines and appear to be equivalent to the shear rate range of 200 to 700 reciprocal seconds.
3. Grease viscosity has a smaller temperature coefficient than that of the oil in the grease even when both are considered in the same viscosity range. This is obviously not true in the extremely low temperature range where grease viscosity and oil viscosity are parallel.
4. The torque-temperature curve appears to be a straight line until the oil viscosity begins to predominate, at which temperature it bends off and is parallel to the oil viscosity line.

We believe that the future technology of grease testing rests on the theory that torque in a given bearing is for the most part, proportional to grease viscosity at the shear rate in use. We realize, on the other hand, that there are conditions such as channeling or grease flowing in a different manner as the grease cools which make the shear rate vary or even introduce other variables which may cause the apparent viscosity to deviate from that obtained by means of capillary flow. In our opinion, however, these factors should not be considered as making the torque-viscosity or dispensing-viscosity correlation untenable or the capillary viscosity unreliable, but rather that the deviation from capillary viscosity should be used *to explain* the action of the grease in the bearing.

(2) M. H. Arveson, Ind Eng. Chem., *24*, 71 (1932); *26*, 638 (1934)

The INSTITUTE SPOKESMAN

Published monthly by

THE NATIONAL LUBRICATING GREASE INSTITUTE

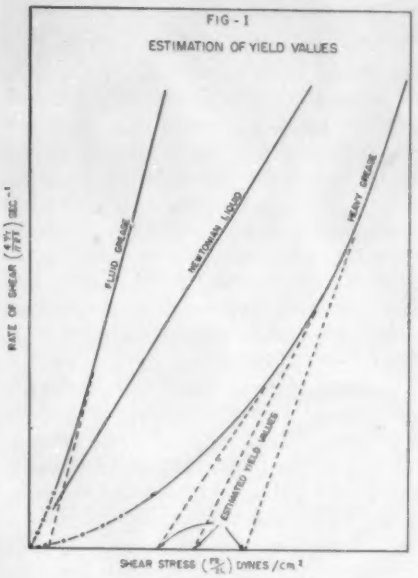
GEORGE W. MILLER ..... *Editor*

498 Winspear Ave., Buffalo 15, N. Y.

Notes on the Operation and Applications of the S. O. D. Pressure Viscometer

(Continued from Page 1)

greases it is less well defined. In fact, there are two different methods now employed for estimating yield values. The first method is illustrated in Figure 1 where the linear portion of a plot of rate of shear versus shear stress (linear scale) is extrapolated to zero rate of shear (zero flow) and the intercept on the shear stress axis is taken as the yield value. The second



method, Figure 2, is to plot rate of shear versus shear stress on a log-log scale and extrapolate to infinitely low rates of sheer. While the results of these two methods do not agree, empirical comparisons or correlations may be based on either method as long as the particular method is specified.

II. THE S. O. D. PRESSURE VISCOMETER

In a paper presented by Messrs. Beerbower, Patberg, Sproule and Zimmer at the 1942 meeting of the National Lubricating Grease Institute, a description was given of a new pressure viscometer, called the S. O. D. Pressure Viscometer, which was especially designed for measuring the viscosities of greases under wide ranges of pressure and rates of shear. The S. O. D. Pressure Viscometer, like most comparable equipment of the capillary type, requires the measurement of the pressure causing metered flow through calibrated orifices. The principle advantages of the S. O. D. Viscometer result from the use of the constant volume displacement pump, Zenith 1B, which lends compactness, simplicity and ease of operation to the instrument, yet maintains the desired accuracy and reproducibility.

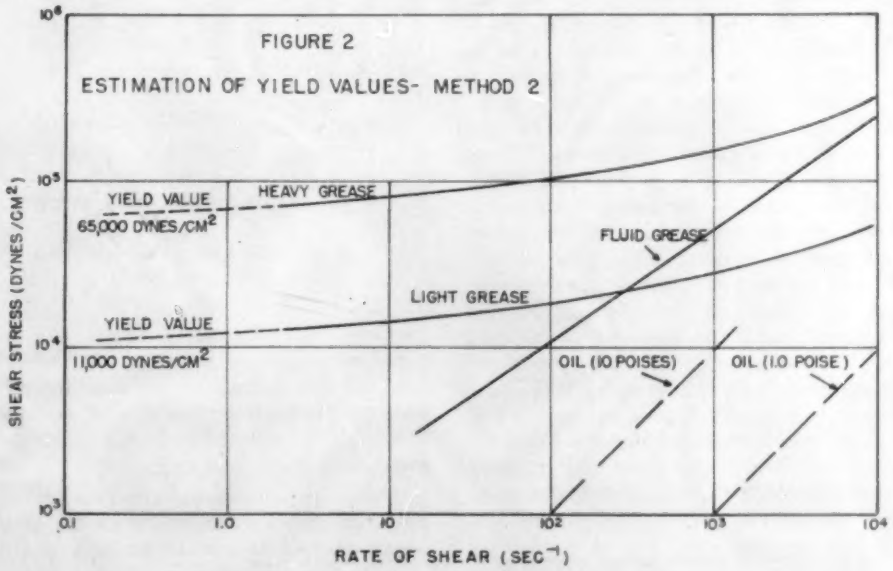
A commercial model of this viscometer has been made by the Precision Scientific Company, Chicago, Illinois, and units such as the one shown in Figure 3 are now in use throughout the country. While the technique of operation may be modified in some ways the following is suggested on the basis of a good deal of experience.

A. Assembling the Apparatus

The photograph which is reproduced in Figure 3 should be sufficient guide for the assembly of the viscometer. Suitable wrenches are supplied as part of the equipment. All fittings, which require frequent use, are either straight threads or high pressure unions and moderate tightening with the proper wrenches is all that is required and recommended. Care should be taken not to jam the vent valve by excessive tightening. The pump is held in its mount by two opposing hollow bolts which also serve as part of the hydraulic system. These should be tightened sufficiently to prevent leaking at high pressures, but not so tight that the pump cannot be easily thrown out of gear, if it becomes jammed.

B. Choice of Hydraulic Oil

An oil having a viscosity of 2,000-2,500 centistokes at the test temperature should be employed as the hydraulic fluid in the unit in order to avoid appreciable pump slippage or leakage at 1,000-1,500 lb./in. ^{2}. An oil of this viscosity also satisfies the other requirement that it must flow readily to the pump under its own hydrostatic head.



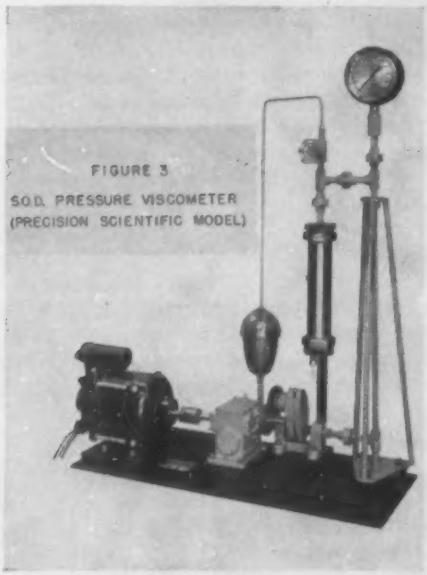


FIGURE 3
S.O.D. PRESSURE VISCOMETER
(PRECISION SCIENTIFIC MODEL)

C. *Filling the Hydraulic System and Charging the Cylinder*

It is important that the hydraulic system and grease cylinder should be filled in such a way to eliminate substantially all the trapped air. The following technique has proved satisfactory. With the gauge disconnected at its union, and the cylinder unit removed at the union connecting the two vertical hydraulic pipe lines, the reservoir is filled and the hydraulic oil is pumped until the line is full. The cylinder unit is then put in place in an inverted position with the capillary-holding cap and the piston removed. The few inches of pipe between the gauge and its union is filled by pouring oil from a small beaker, inverting and fitting the union together quickly. The remaining part of the system is filled by pouring the hydraulic oil into the open end of the cylinder up to the threaded part on the inside. The piston is put in place and, after trapped air is allowed to escape, the vent valve is opened and the piston is allowed to settle until its top surface is flush with the junction of the inside cylinder threads and the smooth walls. The vent valve is closed, excess oil is removed from the inside of the cylinder above the piston, and the grease to be tested is smoothed down into the cylinder against the piston with care to prevent entrapment of air. A vacuum system, with a suitable trap for the displaced oil, is applied to the vent valve which acts as a control and, as the piston slowly draws the grease along with it into the cylinder, the supply is replenished until the cylinder is full or contains enough grease for the desired test. The cylinder cap and capillary are put in place, the valve closed, the cylinder unit returned to its normal position and the test run is begun.

D. *Making a Run*

If the system is free from air, the pressure should begin to rise immediately after the pump is started. When equilibrum pressure is reached, the pump is stopped and the pressure is relieved by venting the excess oil back to the reservoir until the gauge reads zero. This is done to conserve the grease charge. The choice of the gauge depends upon the pressure range. Since each gauge is most accurate in the middle third of its scale, the pressure should be measured on a gauge that includes the value in its range of best accuracy.

The vent valve is closed, the capillary is changed and the above process is repeated until the series is completed. Then the gear on the gear box output shaft is replaced by its alternate (40 or 64 tooth) and the series of tests with the several capillaries repeated. The pressures are tabulated along with the corresponding capillary numbers and type of gear used. At the end of the run the capillaries are blown out with air, soaked in kerosene, or naphtha, then blown dry. The cylinder unit is again inverted at the union, the cap removed, and the piston brought into the filling position, flush with the threads, by pumping oil. When the grease has been removed the unit is ready for the next determination.

E. *Calibration of the Capillaries and Gauges*

Eight capillaries and four gauges are part of the equipment supplied by Precision Scientific Company and oils of known viscosity are available for the calibration of the capillaries. The same technique is employed as in the above viscosity measurements. The pressure, oil viscosity, flow rate and capillary length are known or determinable and when these are substituted into Poiseuille's equation the equivalent viscometric radii may be calculated.

$$\text{Radium (cm.)},\ R = \left[\frac{8\,L\,\eta\,v/t}{\pi P}\right]^{1/4}$$

L = Capillary length (cm.)

η = Poises; $\dfrac{\text{(centistokes x density)}}{100}$

v/t = Flow rate; (cc./sec.)

P = Dynes/cm.^{2}; (PSI x 68,946)

For very low pressures it is advisable to make corrections for the weight of the piston and the hydrostatic head of the oil. However, it has been found that capillary No. 1 can be measured accurately enough by mechanical means.

The gauges should be calibrated against reference gauges or preferably by the dead weight method at regular intervals, and a calibration curve of corrected pressures should be drawn up unless satisfactory adjustment of the gauge can be made. Unless absolutely necessary, no gauge should be used above the three-quarter point of its scale or below the first quarter.

F. *Calculation of Data*

The viscosity data are calculated by substituting determined values for the variables in Poiseuille's equation. These calculations can be simplified considerably, since only the pressure and flow rate are variables. Each capillary has a shear rate constant, which is a function of its radius, and a shear stress constant, which is a function of its length to diameter ratio.

(1) Shear Rate Constant (K_s)

$K_s = \dfrac{4}{\pi R^3}$ is used to calculate the rate of shear (S) from the equation $S = K_s\,(v/t)$ where (v/t) equals cc./sec. and S is expressed in sec. $^{-1}$ units.

(2) Shear Stress Constant (K_f)

$K_f = \dfrac{K_1 R}{2L}$; where $K_1 = 68946$ and shear stress, F = p.s.i. x K_f. Then apparent viscosity, $\eta\alpha = \dfrac{F}{S}$.

For a given flow rate the calculation is further simplified, since for each capillary the viscosity is now a function of only pressure, and a new constant may be derived for each capillary, namely $\eta\alpha = /p$, or, $Kp = \dfrac{K_f}{K_s \times (v/t)}$, and $\eta\alpha = Kp \times p$ where p = p.s.i. gauge pressure. Each capillary has two constants (Kp) since there are two flow rates. This brings us to

G. *Flow Rate Determinations*

The pump delivery rate can readily be determined by measuring the volume displaced during a measured time interval at some constant pressure, preferably one in the region of 1,000 lb./in.^{2}, to check against leakage and pump slippage at high pressures. If the pump will not deliver 0.584 cc./rev. ($\pm 2\%$) at high pressures, the pump plate screws should be tightened or a calibration curve, delivery versus pressure, should be obtained for use in the viscosity studies. This could best be obtained during the capillary calibration procedure. Once the delivery rate (cc./rev.) has been thus determined, the flow rate may be checked by clocking the pump speed, unless, of course, the pump has been subjected to abnormal strain or excessive use. It is good technique to check the delivery rate after a month of normal use and the pump speed during each run.

III. METHODS OF TEMPERATURE CONTROL AND THE PROBLEMS INVOLVED

A. Room Temperature Range

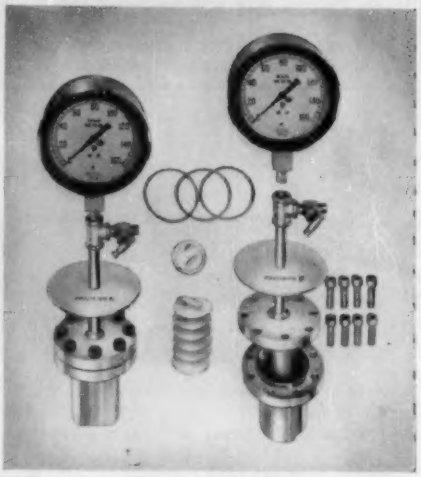
Temperature control in the room temperature range is best effected by means of an air bath completely enclosing the viscometer. Ample room should be made available for changing the capillaries quickly and easily to prevent fluctuation of the grease temperature. Although most greases do not have a large thermal coefficient of viscosity at room temperature, the reference point has arbitrarily been set at 77°F.±½°F. Of course, the heavy calibration oils have high viscosity-temperature coefficients and the more closely the temperature is controlled the more accurate the calibration.

B. Elevated Temperatures

In the temperature range from 77°F. to 350°F. adequate temperature control is obtained by enclosing only the cylinder and capillary in an oven which is equipped with variable control heaters and a thermostat. Since the pump is operating at room temperature the hydraulic oil flow rate will be less than that of the grease when it is flowing at elevated temperatures.

(To Be Continued)

TESTING ★ TOPICS



REVISED NORMA-HOFFMAN GREASE STABILITY BOMB

According to ABEC-NLGI specifications technical bulletin No. 4.

THESE bombs are constructed of 18-8 stainless steel throughout with flanged disc for mounting in bath and are capable of withstanding working pressure of 180 psi at 210° F. They are provided with lead gaskets for perfect sealing. The interior surface of the bomb, lid and pipe carrying the pressure gage is highly polished to facilitate cleaning.

The volume of the bomb, measured to the level of the gage and/or valve connections and without dish holders or dishes is 180 plus or minus 1 ml.

The pressure gage is of the indicating type with a range of 0-160 lb., in single pound divisions, with an accuracy of at least ½ of 1% of the total scale interval.

The Norma-Hoffman, 3-Unit Constant Temperature Bath can also be supplied.

Write for complete information.